# Basic performance evaluation of novel Projection Electron Microscopy (PEM) system for EUV mask pattern inspection

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# Introduction

Detecting the defects of smaller than 18 nm in size is required for the hp 16 nm EUV mask as described in ITRS 2011 edition. In order to achieve the inspection sensitivity and the extendability for 1x node, Projection Electron Microscope (PEM) technique with higher electron energy in imaging and exposure Electron Optics (EO) are developed.

We demonstrated the basic performance of Novel PEM technique by using developed EO.

EO transmittance and image resolution are measured on an evaluation vacuum chamber.

# Defect detection requirement

## EUVL mask requirements (ITRS 2011 edition)

| Year of Production | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|---|---|---|
| DRAM 1/2 pitch (nm) (contacted) | 36 | 32 | 28 | 25 | 23 | 20 | 18 | 16 | 14 | 13 |
| Flash 1/2 pitch (nm) (un-contacted poly) | 22 | 20 | 18 | 17 | 15 | 14 | 13 | 12 | 11 | 10 |
| MPU/ASIC Metal 1(M1) 1/2 pitch (nm) (contacted) | 38 | 32 | 27 | 24 | 21 | 19 | 17 | 15 | 13 | 12 |
| Mask minumum primary feature size (nm) | 99 | 88 | 78 | 70 | 62 | 55 | 49 | 44 | 39 | 35 |
| Defect size (nm) | 29 | 25 | 23 | 20 | 18 | 16 | 14 | 13 | 11 | 10 |

**<18 nm size defects are necessary to be detected by hp16 nm EUVL mask inspection.**

# History and advantages of inspection system using PEM technique

**DUV inspection**

High throughput

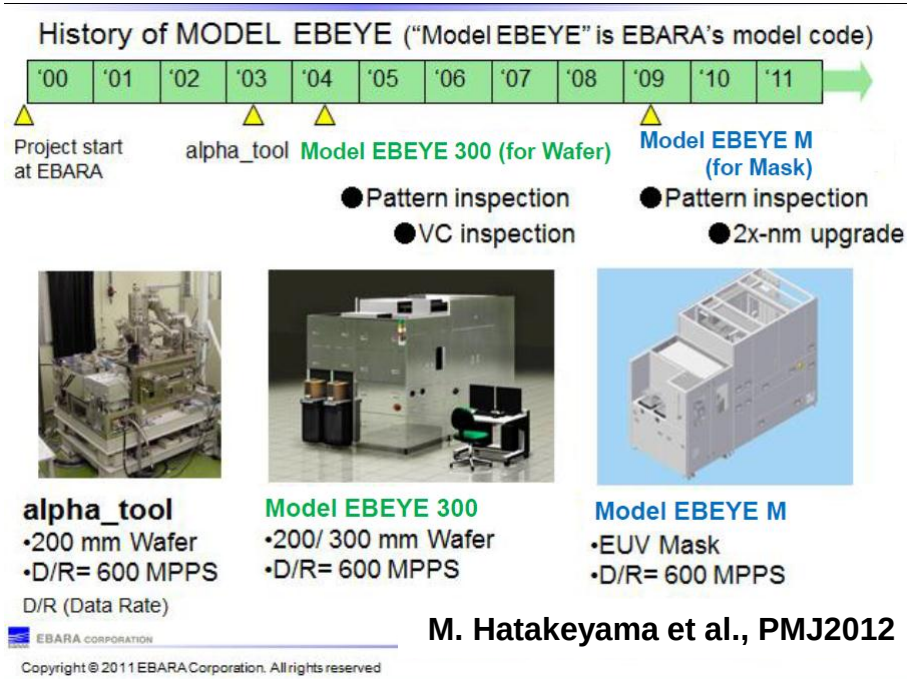
Image resolution limited by λ

**EB-SEM type inspection**

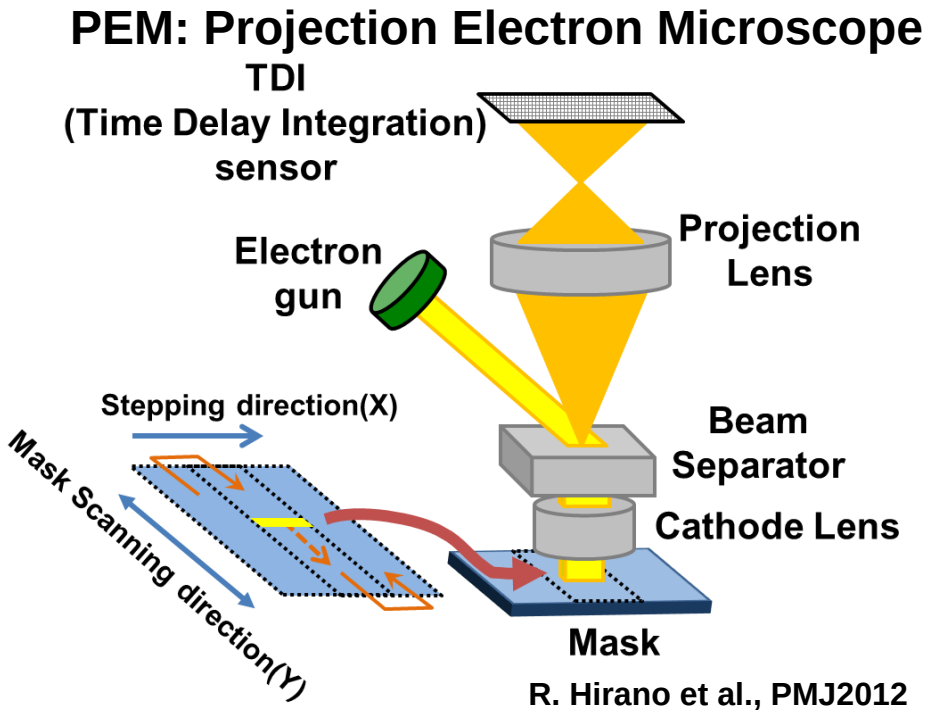
High image resolution

Low throughput(point beam)

**PEM has the advantage of DUV inspection and that of EB-optics.**

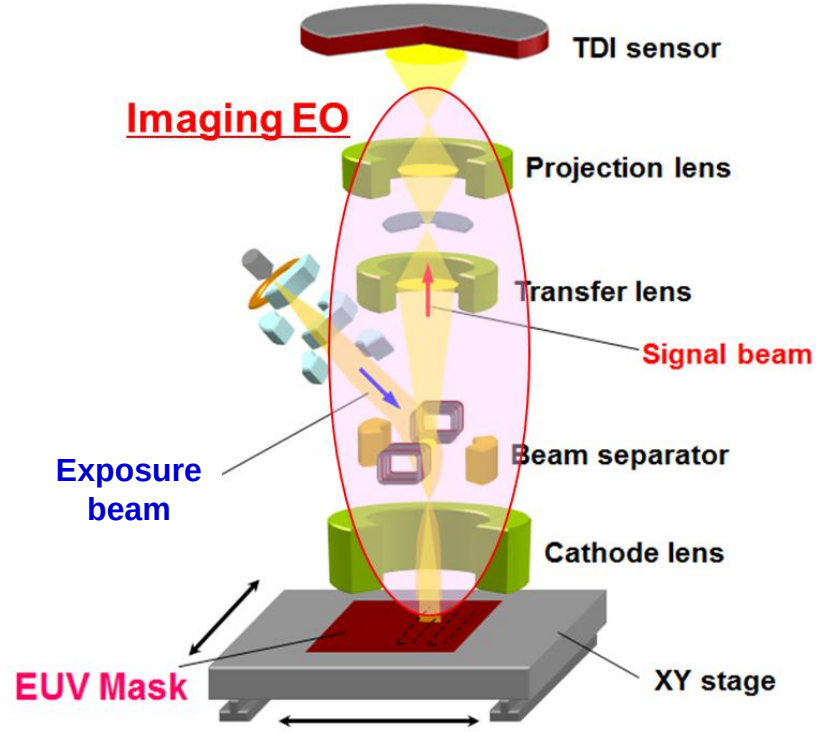



M. Hatakeyama et al., PMJ2012



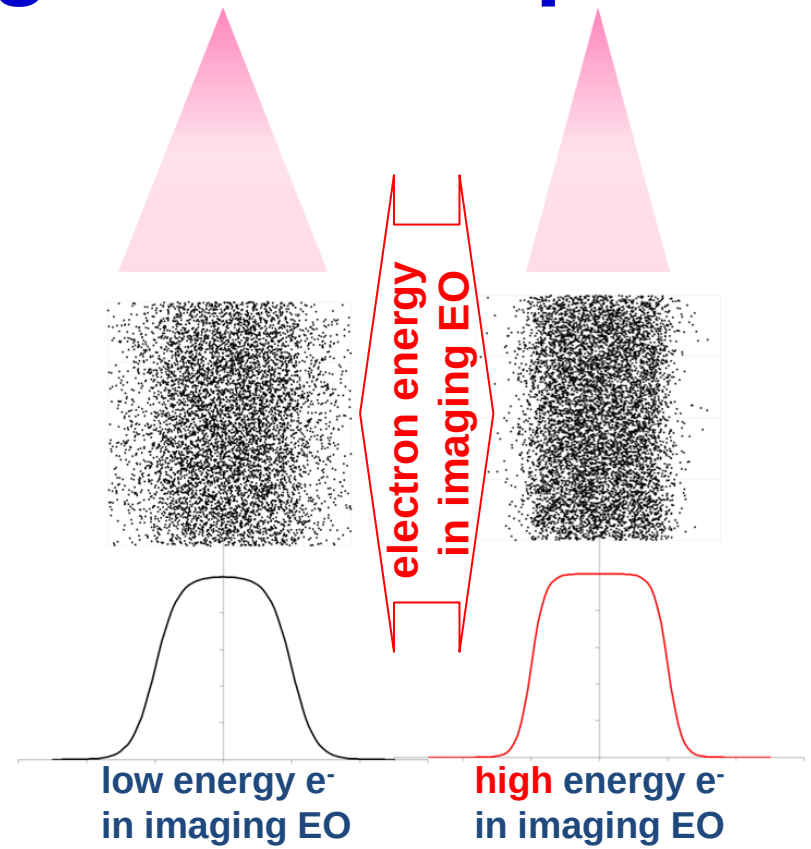

R. Hirano et al., PMJ2012

# Improvement of imaging electron optics




Schematic of PEM PI system (hp 2X nm tool)

T. Hirano et al., SPIE vol. 7823

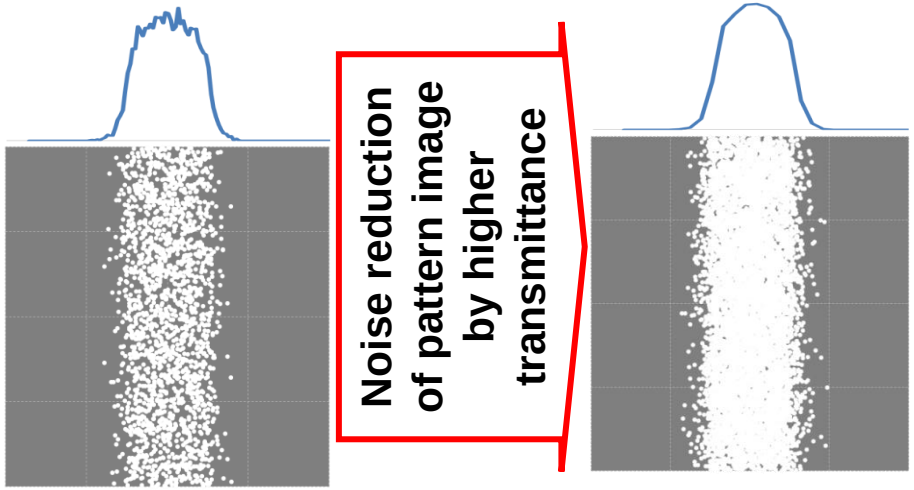


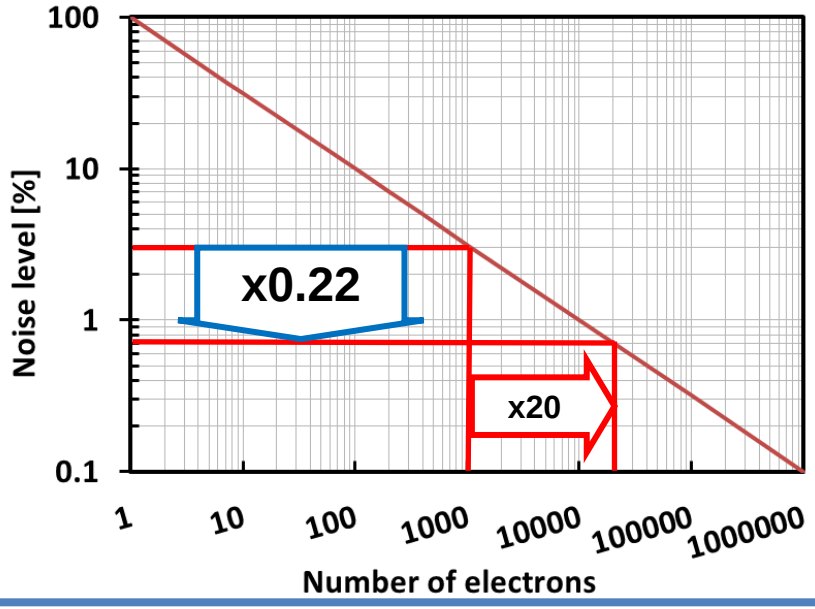

e- profile in imaging EO

**Signal beam profile depends on e- energy in imaging EO. Imaging EO using high energy electron will achieve x1.4 resolution of EO for hp 2X nm.**

# Transmittance improvement in imaging and exposure EO

| | hp 2X nm tool | Novel PEM optics |
|---|---|---|
| Transmittance in imaging EO | 1 | ≧2 |
| Transmittance in exposure EO | 1 | ≧10 |
| Total | 1 | ≧20 |




**Imaging electrons are increased by higher transmittance at same capture rate.**

**More than x20 improvement of transmittance is required on Novel PEM optics are needed. It leads to x0.22 noise reduction comparing to 2X nm tool PEM optics.**

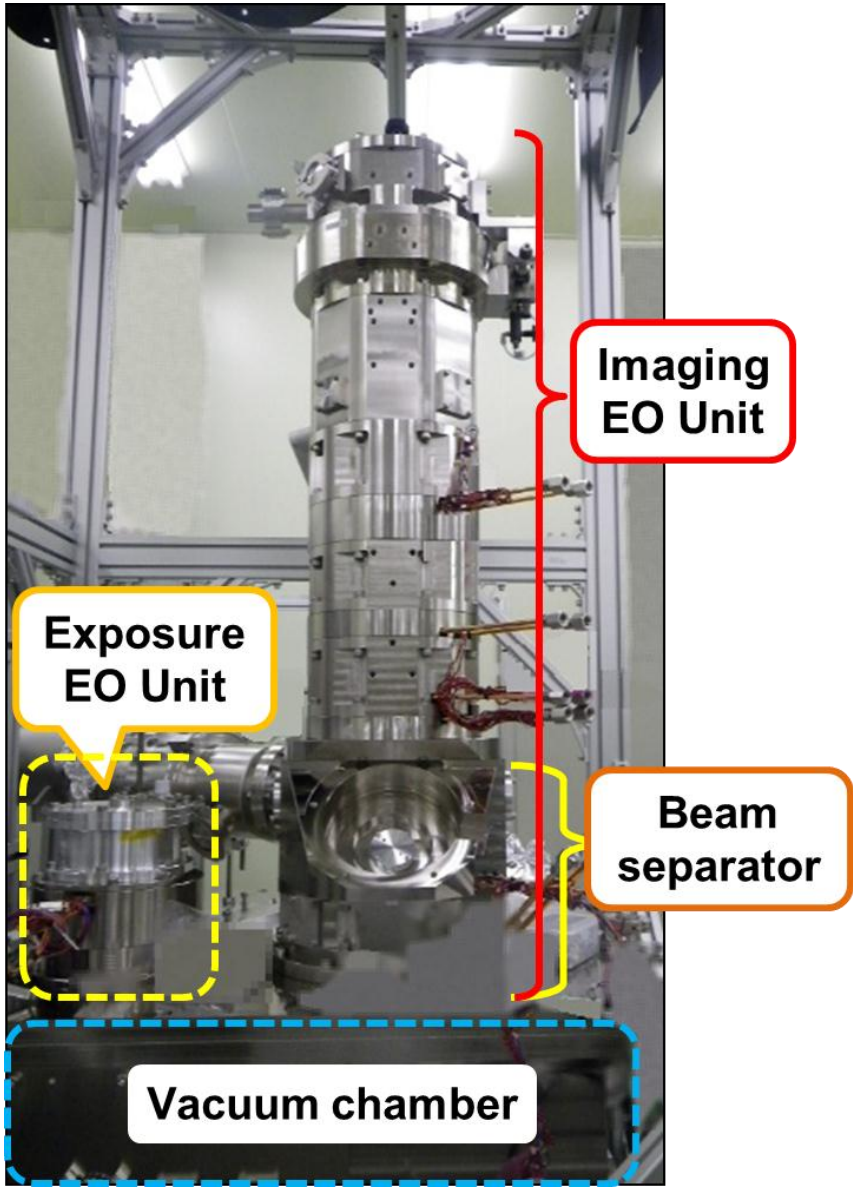
# Novel PEM optics development

**EIDEC developed high resolution and high throughput PEM optics Model EBEYE-V30.**

**We have finished the assembly of newly designed column.**

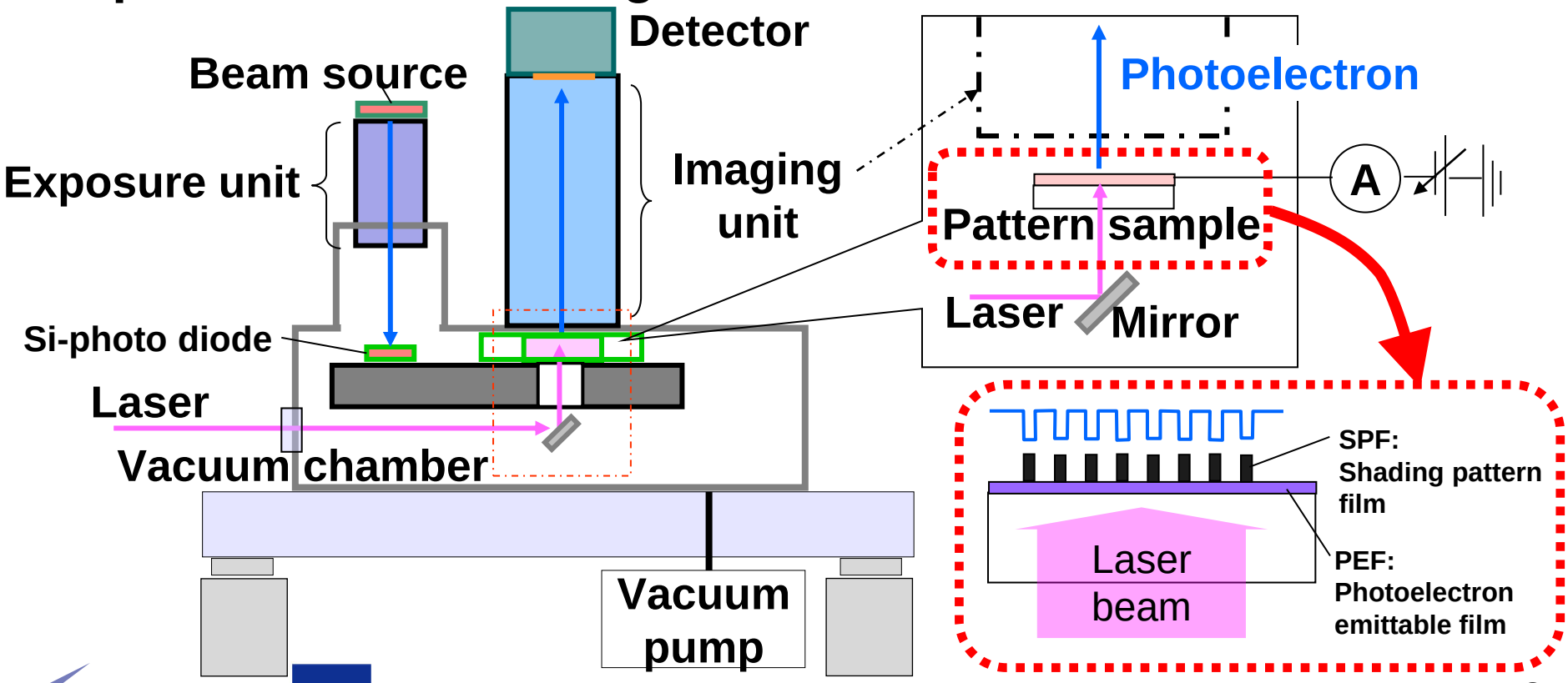
**The column was installed on an evaluation vacuum chamber.**

**Transmittance of exposure and imaging optics were measured. Image resolution of imaging optics was estimated by captured pattern sample image.**

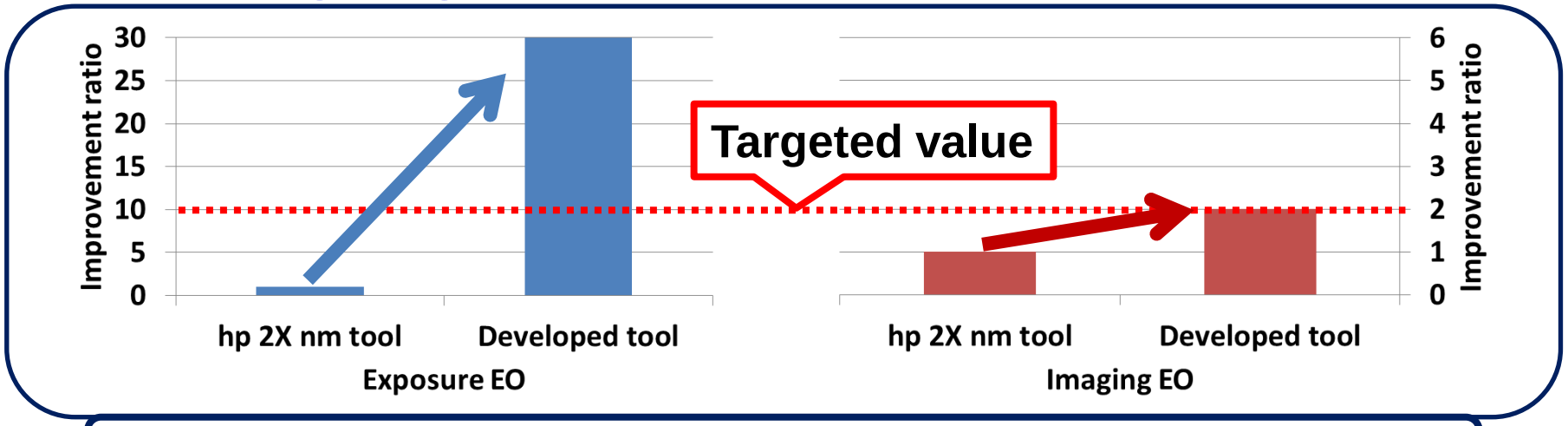


# Evaluation for exposure and imaging unit performance

- ✓ Transmittance of exposure and imaging unit were calculated by the ratio of input to output.
- ✓ Image resolution was evaluated by measuring sample pattern electron image.



# Transmittance evaluation of exposure and imaging unit




**Transmittance improvement design of developed PEM optics**

**Transmittance of exposure and imaging unit were measured by the ratios of input to output.**

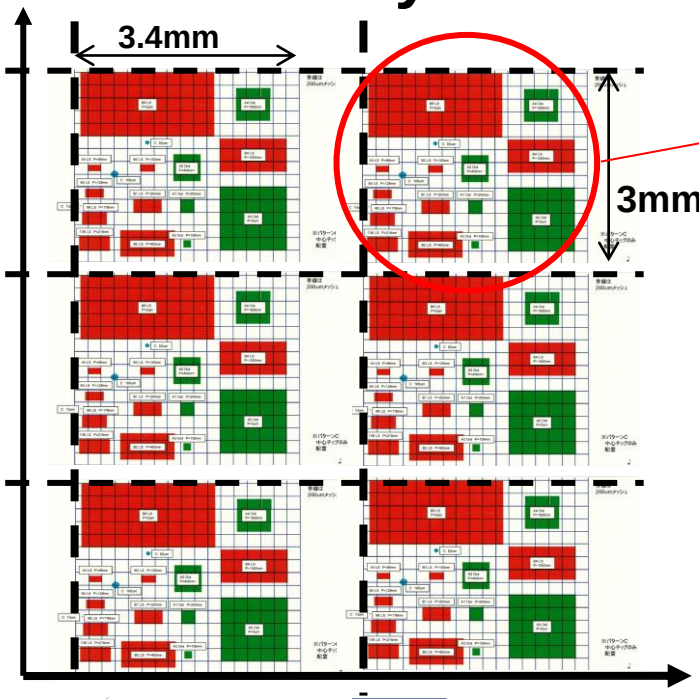
- ✓ **Exposure EO : (Si-photodiode) / (Beam source power)**
- ✓ **Imaging EO : (Detector) / (Photoelectron)**

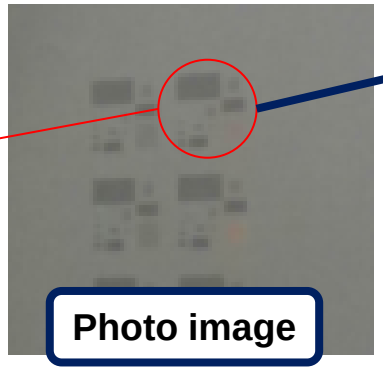
**Designed transmittance of exposure and imaging EO were confirmed by measurements.**

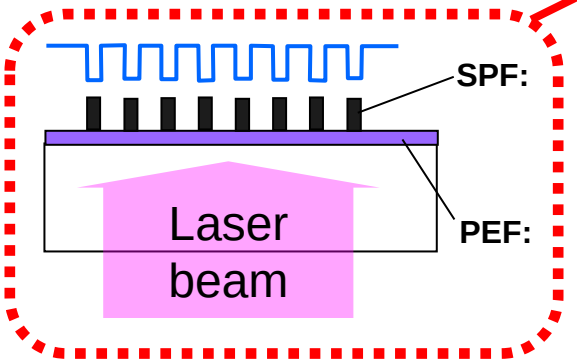
# Pattern sample for imaging unit performance evaluation

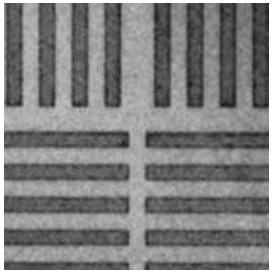
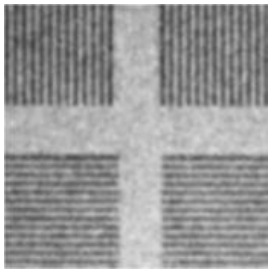
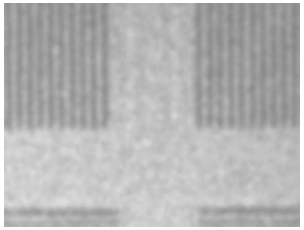
**hp 1 um to 64 nm patterns were fabricated on pattern sample.**

**Electron image was acquired using the sample patterned mask made of shading pattern layer on photoelectron emitting film illuminated by DUV laser.**



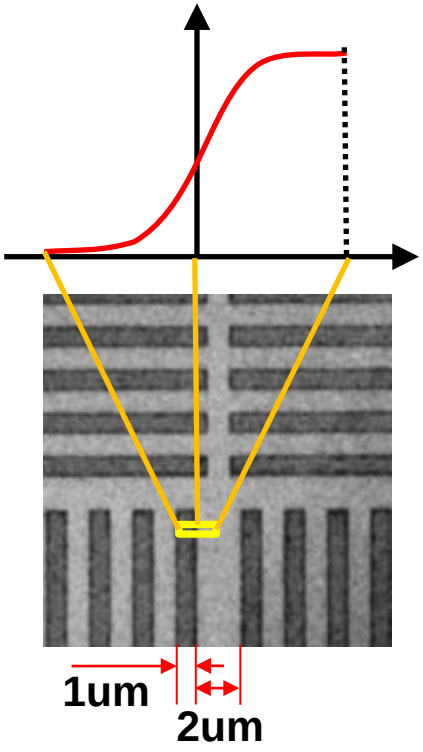



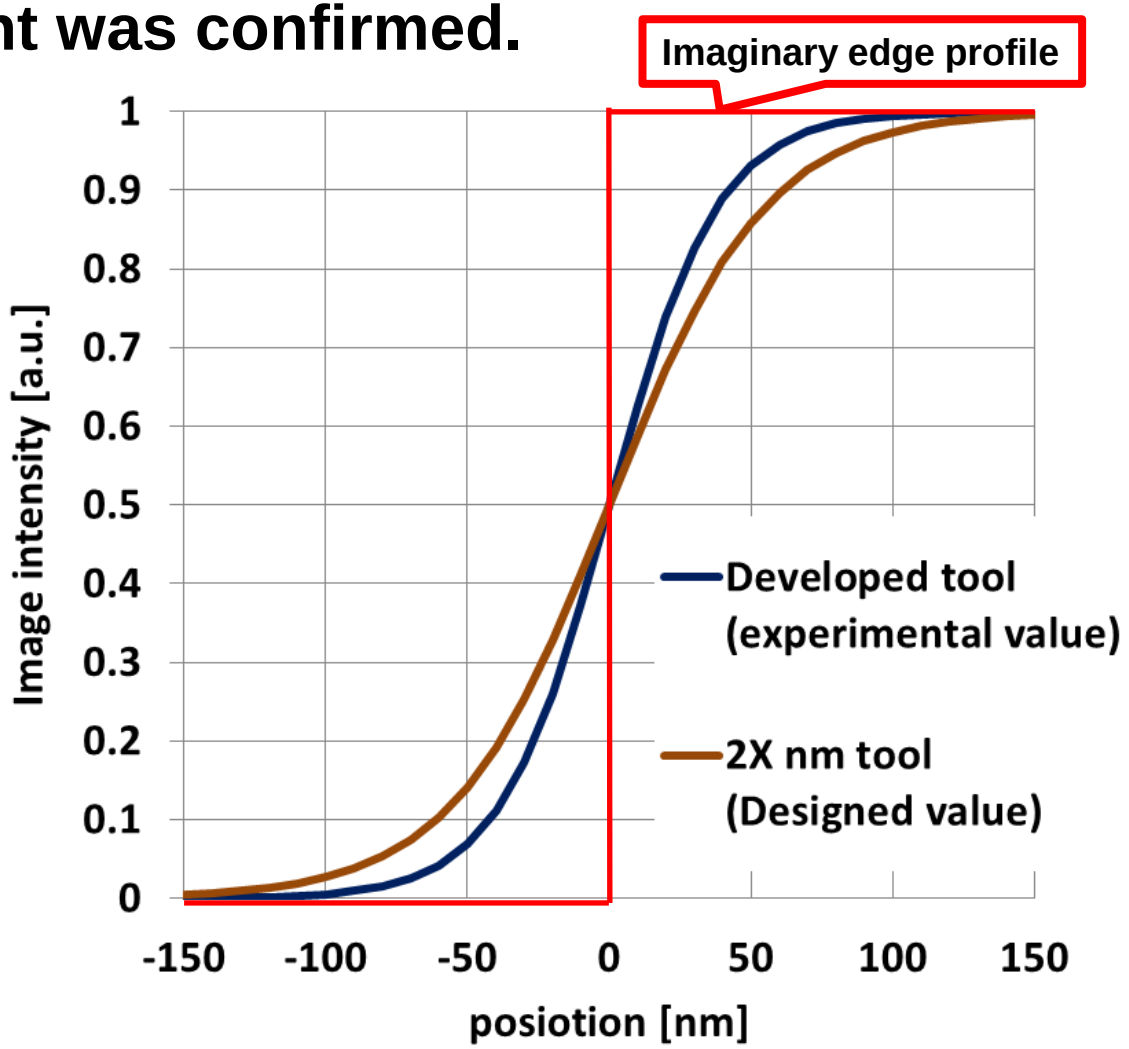




| Electron image of pattern sample |
|---|
|  hp 1um L/S |
|  hp 100 nm L/S |
|  hp 64 nm L/S |

# Image resolution evaluation

**Edge slope was calculated from captured image.**
**Compared with 2X nm tool designed value, expecting image resolution improvement was confirmed.**

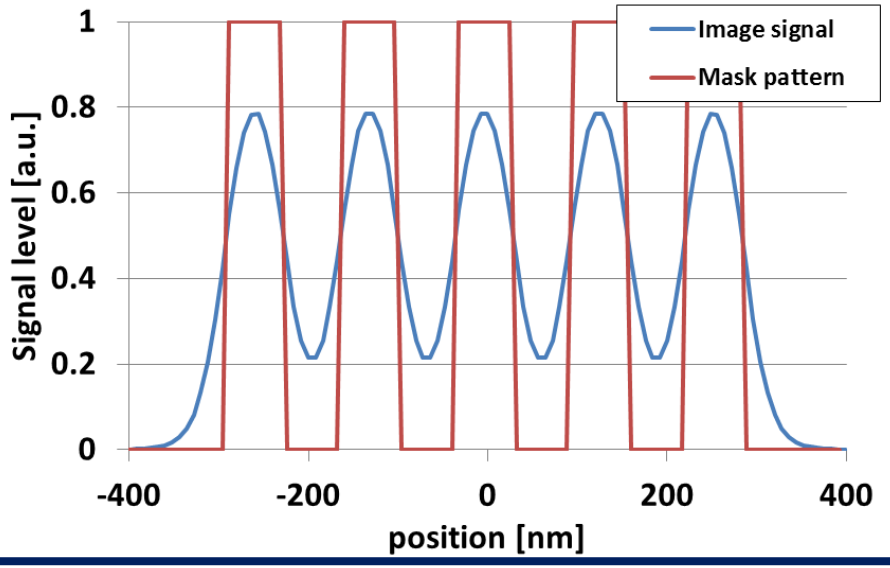


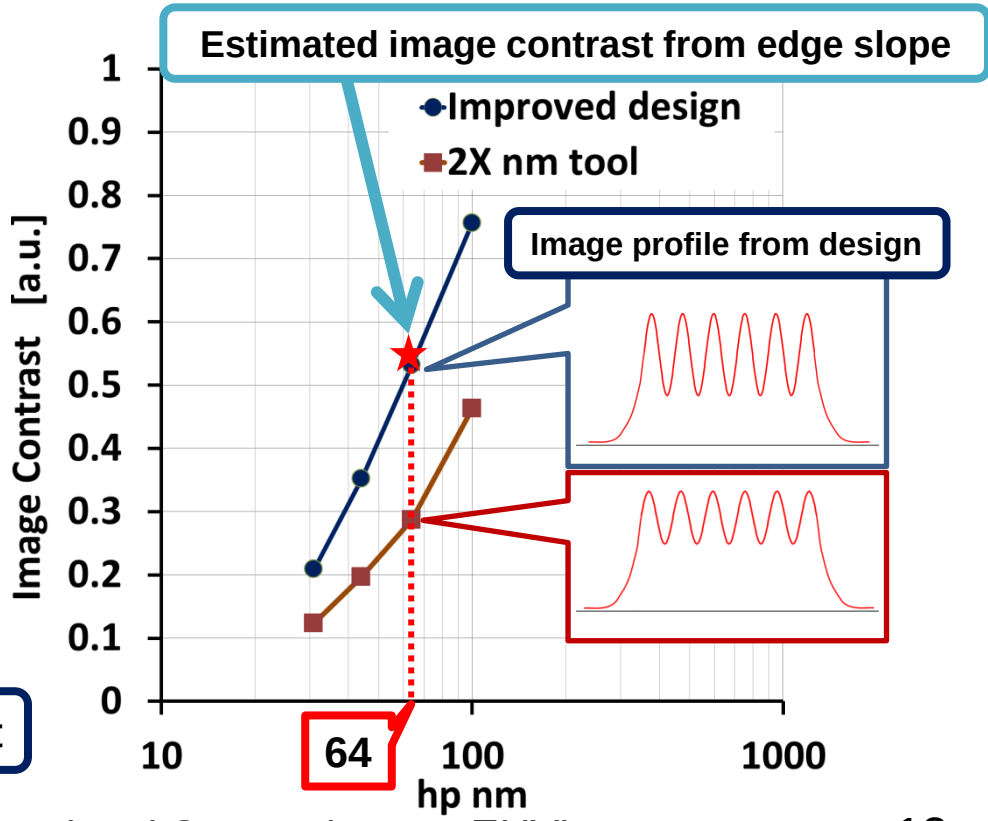
# Image resolution evaluation (cont'd)

**Line spread function (LSF) is obtained as the differential of measured edge profile. L/S pattern profile image can be calculated as the convolution of the LSF with L/S pattern rectangular wave.**

**Estimated image contrast at hp 64 nm pattern was consistent with designed value.**




**Calculated hp 64 nm profile from experiment**



# Summary

**The basic performance of Novel (PEM) technique was demonstrated using developed EO.**

- **Transmittances of exposure and imaging unit were measured as the ratio of input-to-output electrons. The values were confirmed to be exceeding the designed values.**
- **Image resolution was evaluated from sample mask electron image.**
- **Obtained hp 64 nm image contrast was consistent with designed value.**
- **The developed EO has a potential to realize EUV mask pattern inspection for hp 16 nm generation and beyond.**

# Next step

**Basic performance evaluation of integrated exposure and imaging optics**

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